ON THE NATURE OF THE PALLASITE PARENT BODY: MIDCOURSE CORRECTIONS. John A. Wood, Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138.

In two relatively obscure references (1,2), I have argued that the pallasites can be understood as the equilibrium product of buoyancy forces at the core-mantle interface of an internally melted small planet (Fig. 1); but that unless the planet was very small ($\lesssim$10 km radius), the buoyant forces pushing olivine crystals up against the overlying cumulate system that kept the crystals pressed down in the molten metal of the core would be great enough to grossly deform the olivine, squeeze the metal out of interstices, and destroy the characteristic pallasite texture. It seemed necessary to postulate a two-stage history for the pallasites, wherein these meteorites were formed in a <10 km body, but were then incorporated in a much larger object (>100 km radius) before they cooled through $\sim$500°C, where their relatively slow cooling rates ($\sim$0.5°K/10^6 yr) were recorded.

The maximum stresses due to buoyant forces are felt at level R_2 in Fig. 1; the stresses taper to zero at R_1. One element of my argument, embodied in Fig. 6 of (2), was that even if we write off the pallasitic material near R_2 and consider the situation near R_1, the stresses are still prohibitively high in a >100 km body, too great to permit the survival of the pallasitic structure. Fig. 6 of (2) indicates that this would be the case even within 0.01 cm of R_1!

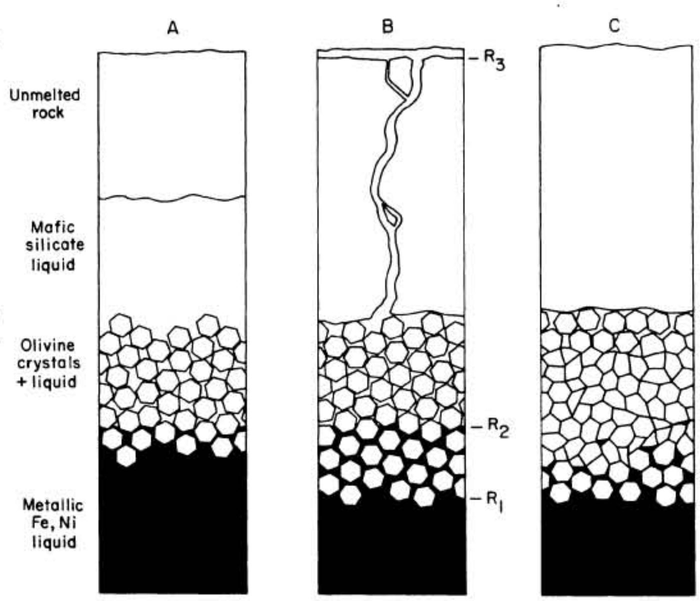

Fig. 1. Radial columns in an internally melted small planet. A: The case where a solid shell of unmelted rock is supported by its own strength. Olivine crystals, slightly denser than the enclosing mafic silicate liquid, form a cumulate layer at the interface between immiscible silicate and metal/sulfide liquids. The weight of the cumulate layer presses the lowermost olivine crystals down into the dense metal/sulfide liquid. The depth of submersion is such that the upward buoyant forces exerted by olivine crystals in metal/sulfide liquid balances the weight of the cumulate layer above the interface. B: A more realistic system than A, in which mafic liquid is able to erupt to the surface and the weight of all the solid layers of the planet rests on the olivine cumulate layer. This additional weight gives rise to a thicker layer of submerged olivine crystals (R_1-R_2; potentially pallasites). C: The same directed stresses that submerge olivine crystals in liquid metal/sulfide tend to deform the olivine crystals, which are weak at the temperature of molten iron. Crystals would tend to close up together, squeezing metal/sulfide liquid downward and mafic silicate liquid upward and eliminating the pallasitic layer in favor of a zone of dunite.

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THE PALLASITE PARENT BODY

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R.J. Greenberg has pointed out an error in the derivation of this last point. Fig. 6 of (2) assumes that strain is directly proportional to stress, whereas according to my own earlier development it scales as the 2.91 power of stress. Thus while the curve representing stress vs. strain at R_2 in Fig. 6 remains nominally correct, the additional stress/strain curves for positions 10^{-1}, 10^{-2}, etc. of the way from R_1 to R_2 are too high in the diagram. A corrected version of this figure appears as Fig. 3 of the present paper.

Another correction that I believe should be applied to the situation has to do with the cooling rates of pallasites. In (3) I compared the cooling times of five meteorite classes as derived from their metallographic cooling rates with the cooling times dicated by their gas retention ages, and found the latter systematically shorter than the former by about a factor of six. Ref. (3) concludes that either the metallographic cooling rates are too slow by a factor of six, or the thermal histories of meteorite parent bodies were much more complex than have been allowed for by published studies. Ref. (3) pursues the second of these possibilities, but I have since been persuaded that the factor-of-six error is more likely; partly because fission-track cooling rates, which previously had been in broad agreement with the metallographic cooling rates, have now been increased by a similar factor (4). The reason for such a discrepancy in metallographic cooling rates remains unknown.

The apparent cooling rates of pallasites are $\sim 0.5°K/10^6$ yr (5). Correcting these by 6 x brings them to $\sim 3°K/10^6$ yr. This cooling rate would obtain at a depth of ~ 70 km in bodies having a wide range of overall dimensions (6, Fig. 26). Cores in totally melted and differentiated bodies of chondritic composition would have radii $\lesssim 0.5$ the total planetesimal radii. Thus parent body radii $\gtrsim 150$ km are indicated. From Fig. 3, it can be seen that most of the potential pallasitic material in such a large body is still vulnerable to destruction by deformation. Fig. 3 indicates that no more than 10^{-3} of the thickness of the pallasitic layer that buoyancy forces could form would survive.

Chemically, pallasites are akin to Group IIIA and/or B medium octahedrites (7). These can reasonably be thought to have come from the same parent body. The ratio of pallasites to IIIAB's in our collections is 35/146 (7). Here I have counted finds as well as falls, making the assumption that irons and pallasites are equally bizarre and "collectible" by people who stub their toes on them. If we take these numbers as indicative of the

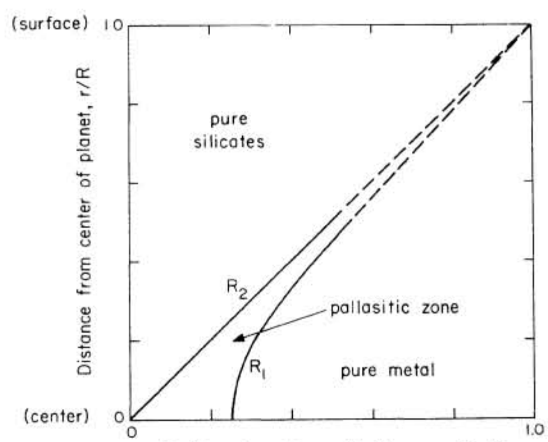

Fig. 2. Equilibrium positions of the R_2 and R_1 levels (which define the thickness of the pallasite zone), as a function of the total size of the metal + pallasite zone (the core) (1,2). All values are relative to the overall radius of the planet (R); the relationships are independent of absolute size. Dashed portions of curves correspond to unrealistically large cores, larger than would be produced by total melting and differentiation of ordinary chondrites.

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volumes occupied by the two types of material in a single parent body, they reduce to the relationship $R_1 = 0.921R_2$ for Fig. 1.

From Fig. 2 the equilibrium thickness of a buoyantly supported pallasite layer in a body where R_2 is half the total radius is $\sim 0.1R_2$, or $R_1 \sim 0.9R_2$. Thus to account for the proportions of pallasites and IIIAB octahedrites, most of the pallasitic material ($\sim 2/3$ of it) that buoyant forces could create would have to survive. From Fig. 3, it can be seen that this much pallasite could not survive unless the parent body had a radius less than ~ 15 km. Errors of a factor of several in the ratio of pallasites to related irons do not change the situation appreciably.

Therefore a major discrepancy still remains in the apparent size of the body in which the pallasites crystallized, and the size of the body in which they cooled through 500°C. A two-stage planetary history remains a possible solution to the problem. It appears that nothing is different. However, this is not the case: there is a qualitative change in the situation. According to (1,2), essentially no pallasite material could survive in a body large enough to be consistent with the pallasite cooling rate. Now it appears that some can survive, though not enough to account for the museum statistics. If buoyancy forces could sustain a 7-km-thick zone of pallasite material in a 150-km-radius planetesimal, and if only 10^{-3} of this survived deformation, this is still a 7-m layer of stable pallasites. The most likely resolution of the discrepancy is simply that the proportions of pallasites and Group IIIAB irons in our collections are grossly non-representative of their abundances in the (>150 km) parent object. Pallasites would be more readily spalled off a core remnant by collisions than pure metal samples would be, after all, since the pallasite layer is exterior to the metal and is also weaker.

In this case it has to be a coincidence that the pallasite/IIIAB ratio in museums (0.24) agrees as well as it does with the volume ratio of pallasitic material to metallic core material in a buoyantly equilibrated system (0.37, assuming a core radius 0.5 that of the planetesimal).

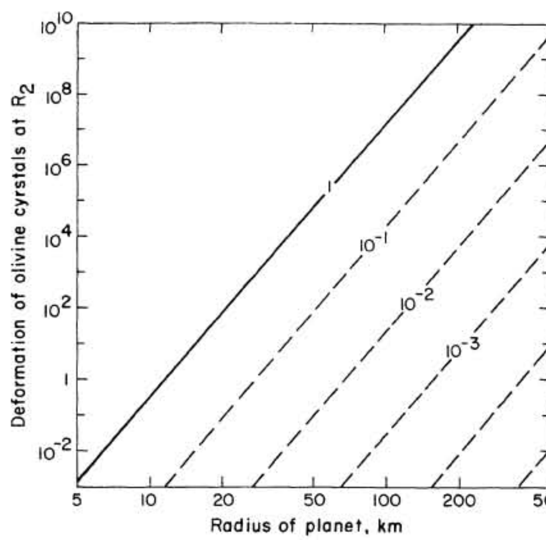

Fig. 3. Curve 1: degree of deformation experienced by olivine crystals at R_2 in Fig. 1 during cooling of the parent planet, as a function of planetary radius (2). A value of 1.0 corresponds to deformation of a right angle into a 45° angle. Other curves show deformation at radii r in the planet, such that $(r-R_1)/(R_2-R_1) = 10^{-1}$, 10^{-2}, etc.

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